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Subject review

Possibilities of Pervious Concrete Application in Road Construction

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Abstract: The paper presents basic characteristics of pervious concrete and gives an overview of the most significant current researches in the world as well as the possibility of use of pervious concrete for road construction in Western Balkan's countries, like Serbia. The analysis of the recent researches is presented in the form of diagrams and correlations between physical and mechanical properties of pervious concrete. During the preparation of this type of concrete, it is observed that the aggregate has the most significant influence since it represents 70 to 80% of the total concrete volume, followed by the binder type, by the water-cement ratio and finally, by the additives within the concrete mixture. For the concrete preparation, recycled and light aggregates, with or without addition of small size aggregate (sand), were used. In general, all three aggregate types can be used for pervious concrete mixtures thus promoting the use of recycled aggregates and, by doing so, also supporting conservation of natural resources. Worldwide, pervious concrete is most often used for roads with light traffic, pedestrian and cycling path sand, therefore it could be used more often in Western Balkan countries for similar purposes.

Keywords: application; pervious concrete; physical-mechanical properties; road

1 INTRODUCTION

Pervious concrete, owes its name to large proportion of the pores within its structure, which is a consequence of the complete absence or small presence of fine aggregate particles in its composition. According to Putman and Neptune [1], porosity of such concrete varies between 15 and 35%, which was also confirmed by other researchers [2-4]. A large amount of pores is responsible for the biggest drawback of pervious concrete, for its reduced strength. Compressive strength of such concrete is in the range of 20 to 30 MPa [5]. A large amount of pores also provides some advantages to pervious concrete compared to conventional concrete.

Due to high permeability and interconnection of pores, leakage of water is increased for roads constructed with pervious concrete therefore reducing the need for construction of drainage system, reducing the noise and overheating [1]. This way water treatment is also facilitated as well as the improved restoration of dynamic water supply in cities. Thus, pervious concrete is particularly suitable for car parking construction, walking and biking trails, as well as for the construction of porous bases and edge drains and shoulders that reduce the drainage of water below the carriageway [6]. Great porosity of pervious concrete contributes to good sound absorption [7]. Compared to normal concrete, pervious concrete has lower elasticity modulus and less pronounced shrinkage [8-11]. Due to its basic deficiency, reduced strength, tests on pervious concrete are mostly focused on finding the optimal composition that would satisfy the compressive strength criteria.

Compared to construction of typical asphalt based carriageways, less fuel is consumed for production, transport and compaction of materials when concrete carriageway is applied [7]. Industrial by-products (fly ash, slag) can be used for concrete mixtures what reduces the landfill of these materials and also reduces the pressure on natural resources. Contemporary concrete pavements have improved surface texture what makes them a good solution for noise reduction and increased surface slip resistance. These properties are especially not iceable in carriageway structures with top layer made from pervious concrete.

This paper presents the basic characteristics of pervious concrete, some of the contemporary research in the world and the possibility of pervious concrete application in road construction in Western Balkan countries such as Serbia.

2 THE COMPOSITION OF PERVIOUS CONCRETE MIXTURE

Production of pervious concrete requires the same components as normal concrete with the exception of the quantity of fine (small size) aggregate particles. It is mainly made with one fraction of aggregate. Tab. 1 shows the approximate range of component contents for production of pervious concrete mixture.

Table 1 The limit value of the material amount for the production of pervious concrete mixture [2]

Material components	Value range
Cement	270-415 kg/m^3
Aggregate	1190-1480 kg/m^3
Water-cement ratio	0.27-0.40
Aggregate and cement ratio	4-4.5:1
Coarse and fine aggregate fractions ratio	1:0-1

2.1 Cement

Portland cement is used as the main binder, and as additives to Portland cement the following is often used: fly ash, ground granulated-metallurgical slag and silica fume. It is recommended to conduct material testing of the mixture in order to verify compatibility of the mixture and that setting time, workability, strength and porosity can provide the necessary characteristics for the intended use of concrete [2].

2.2 Aggregate

Granulometry of the aggregate, which is used in pervious concrete, is usually related to one size aggregate; with the grain size according to ASTM is C33 No. 67 (4.75-19.0 mm), No. 8 (2.36-8.5 mm) or No. 89 (1.18-9.5 mm). The content of fine aggregate in the mixture of pervious concrete is limited since it jeopardizes interconnectivity of open pore structure. The addition of fine aggregate (sand) can increase the compressive strength and density, but it also reduces the water permeability of the pervious concrete mass. Aggregate quality in pervious concrete is just as important as for the normal concrete. Laminar or elongated aggregate particles should be avoided. Granular aggregate should be hard and clean, free of coatings such as dirt, clay or absorbing chemicals that could have effect on the bond between aggregate and cement paste or the cement hydration. The use of dry aggregate may result in the mixture that is without adequate workability. Overly wet aggregate may contribute to poor cement bonding what causes the distortion of the required pore structure. The ratio of aggregate and cement ranges from 4 to 4.5, in other words, the production of porous concrete mixture aggregate requires from 1190 to 1480 kg/m^3. The coarser aggregate provides hydrological benefits due to large open pores and increased permeability (Fig. 1) [2].

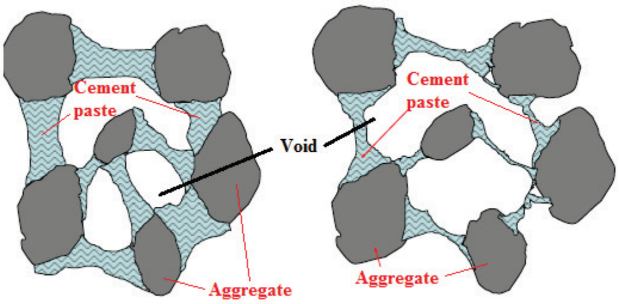

Figure 1 The structure of hardened concrete (left - higher volume of cement paste, right - smaller volume of cement paste and a higher content of pores)

For the preparation of pervious concrete, the following can be used: natural aggregate (natural gravel, limestone, granite, crushed stone) [12-14], recycled (recycled concrete, recycled brick, recycled lightweight concrete) [15-17] and lightweight aggregate [17].

2.3 Water

The water quality of porous concrete has to fulfill the same conditions as for normal concrete. Porous concrete has a relatively low water-cement ratio (usually 0.27 to max. 0.40). The excess water will lead to separation of water from the cement paste and subsequent clogging of pores. The amount of water required for preparation of pervious concrete mixture, can be very easily and quickly determined by taking a handful of concrete mixture and shaping it in a ball, which is observed on the widespread palm. If the ball keeps its shape, the grains do not separate and cement does not separate, mixture has a sufficient water amount (Fig. 2).

(a) small water amount (b) optimum water amount (c) too much water amount

Figure 2 Pervious concrete samples with a different water content [2]

2.4 Additives

Additives for reducing the water amount are used depending on the water-cement ratio. Additives for slowing down the setting and hardening process of the concrete mixture (retarders) are used for the stabilization and control of cement hydration. They are often used when working with solid mixtures, such as pervious concrete. Retarders are especially useful during casting of concrete at high temperatures. These additives can also be useful as lubricants during unloading of concrete from mixers (reducing friction), and can improve the handling and casting properties. Accelerators can be used when pervious concrete is cast at low temperatures. With the use of multiple ingredients in any concrete mixture, it is recommended to cast a trial mixture in order to identify possible incompatibility problems of impurities and to verify that the desired properties of fresh and hardened concrete are consistently achieved. Additives in the form of air entraining admixtures are not normally used in pervious concrete but can be used in environments susceptible to freezing and thawing cycles [2].

3 THE PERVIOUS CONCRETE PROPERTIES

Many pervious concrete properties primarily depend on its porosity, which in turn depends on the cement content, water-cement ratio, density, particle size distribution and general material quality. The pore sizes in the concrete also affect the strength properties. The most important properties and their interdependence, analyzed within this study are:

- compressive strength,
- flexural strength,
- tensile strength at splitting,
- density,
- frost resistance,
- abrasion resistance,
- permeability coefficient,
- porosity.

Mixture composition properties of pervious concrete are shown in the Tab. 2. A brief description is given of the aggregate type, aggregate fractions, chemical and/or mineral supplements and water-cement ratio.

3.1 Compressive Strength

The characteristic compressive strength of pervious concrete is in the range from 2.8 to 28 MPa. The values or mixture ratios as well as effort invested in compaction during casting of concrete have the most effect on compressive strength of pervious concrete. The consequence of the increase of the aggregate size is reduction of compressive strength. Presence of additives such as polymeric additives and mineral admixtures lead to increase of compressive strength while using the aggregates of the same granulation. The total content of cementations material in pervious concrete mixture is important for the development of compressive strength and pore structure [6].

Papers [12-33] also analyze the concrete compressive strength after 28 days, as shown in the following figures

(Fig. 3, Fig. 4, Fig. 5) with different types and aggregate fraction contents, chemical and/or mineral data, and different water-cement ratio (Tab. 2).

Table 2 Mixture composition characteristics of pervious concrete

Paper	Aggregate type	Aggregate fraction (mm)	Participation of aggregate fraction (%)	Chemical and / or mineral additives	Water-cement ratio (m_v/m_c)
[12]	granite	2.36-4.75	93 - 100	aerates and plasticizers	0.27
	gravel				
	limestone				
	sand	0-2.36	0 - 7		
[13]	limestone	2.36-4.75; 4.75-9.5; 9.5-12.5	100	-	0.32-0.33
[14]	gravel	10	90 - 100	fly ash	0.35
	sand	0-3.75	0 - 10		
[15]	diatomite	4.75-9.5	100	viscosity-modifying additives	0.24
	pumice	4.75-9.5	100		
	recycled lightweight concrete	4.75-9.5	100		
[16]	gravel	10-12.7	96 - 100	superplasticizers	0.34
	recycled concrete	10-12.7	96 - 100		
	wood fiber	0-10	0 - 4		
[17]	crushed gravel	8-13; 13-19	100	superplasticizers, aerates	0.20-0.28
	lightweight aggregates (expended shale)	4-8; 8-12; 12-19	100		
[18]	granite	4.75-9.5; 9.5-12.5	100	fly ash, silica fume, additives for viscosity modifying, DJ-601 (a mixture of ethylene vinyl acetate and acrylic polymer emulsion)	0.28-0.34
[19]	quartzite	12.5-19	95	fly ash and slag	0.24-0.31
	pea gravel	4.75-9.5; 9.5-12.5	93 - 100		
	sand	0-4.75	0 - 7		
[20]	limestone	4.75-9.5; 9.5-12.5; 12.5-20	50 - 100	-	0.30-0.40
[21]	river gravel	2.36-4.75; 4.75-9.5; 9.5-12.5	93 - 100	synthetic rubber, silica dust, aerate additive for viscosity modifying	0.22-0.27
	crushed limestone	2.36-4.75; 4.75-9.5; 9.5-12.5	93 - 100		
	pea gravel	2.36-4.75; 4.75-9.5; 9.5-12.5	93 - 100		
	sand	0-4.75	0 - 7		
[22]	basalt	20 / 100	100	superplasticizer	0.28-0.40
[23]	granite	5-13; 13-19 / 100	100	slag	Unknown
	recycled concrete	5-13; 13-19 / 100	100		
[24]	limestone	4.75-9.5	95	natural and synthetic air entraining agents, high-range water reducer	0.27
	pea gravel	4.75-9.5	95		
	sand	0-4.75	5		
[25]	dolomite	0-4; 4-8; 8-16	0 - 60	superplasticizer	0.33
	gravel	4-8; 8-16	0 - 60		
	sand	0-2	10		
[26]	gravel	3-5; 5-10; 10-20; 15-30	80 - 100	silica fume, superplasticizer, vinyl acetate-ethylene emulsion, polyvinyl alcohol formaldehyde hydrosol	0.20-0.35
	sand	0-2.5	0 - 20		
[27]	granite	4.75-12.5; 12.5-20	85 - 95	superplasticizer, viscosity modifying admixture, fly ash	0.21-0.43
	sand	0-4.75	5 - 15		
[28]	gravel	10-12.5	80 - 100	-	0.27
	recycled rubber	0-1; 1-4; 4-8	0 - 20		
[29]	limestone	4.5-9.5	100	sodium hydroxide, sodium silicate	Unknown
	recycled brick	4.5-9.5	100		
	recycled concrete	4.5-9.5	100		
[30]	limestone	9.5-20	100	Unknown	Unknown
	basalt	6.0-8.0	100		
[31]	gravel	10-12.5	80 - 100	-	0.27
	recycled rubber	0-1; 1-4; 4-8	0 - 20		
[32]	limestone	4.75-12.5	96 - 100	retarder, viscosity modifier and cellulose fibers	0.29
	sand	0-4	0 - 4		
[33]	granite	1.18-9.5	93	air-entraining admixture, viscosity modifying admixture, high range water reducer, monofilament polypropylene fiberandlatex	0.26-0.36
	limestone	1.18-9.5; 2.36-4.75	93		
	sand	0-2.36	7		

In Fig. 3, the results of the analyzed research are summarized and the compressive strength dependence of porosity is shown (Tab. 2). The dispersion of the results is big and it is not possible to establish reliable correlation between porosity and compressive strength. A large number of presented results are within a range of 2 to 30 MPa. In general, reducing of porosity will lead to a large dispersion of compressive strength results. Increase of compressive strength is observed with increase of fine aggregate (sand) fraction, as well as additives in concrete.

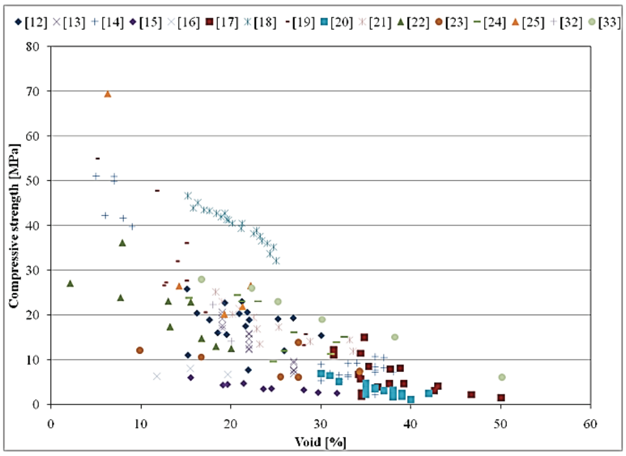

Figure 3 Dependence of compressive strength and void

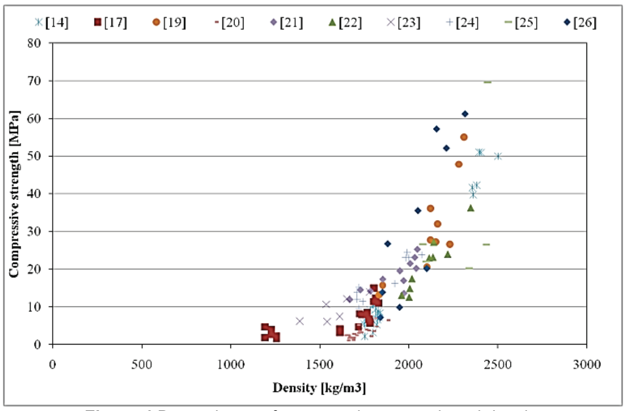

Figure 4 Dependence of compressive strength and density

Fig. 4 summarizes the results of compressive strength and density dependence. Generally, with the increase of density, compressive strength increases and vice versa. According to Fig. 4 it can be clearly seen that the value of density cannot be a reliable indicator for determining of the compressive strength. Different values of compressive strength have the same values of density, and it is observed that the type and size of aggregate fraction significantly affect determination of the compressive strength of pervious concrete. Density is also different due to the presence of small sand particles what further accelerates the increase of both density and compressive strength.

In Fig. 5 the results of compressive strength dependence on water-cement ratio are summarized. Generally, with the increasing of the water-cement ratio, compressive strength decreases and vice versa. According to Fig. 5 it can be clearly seen that the value of water-cement ratio cannot be a reliable indicator for determining the compressive strength and other factors must be taken into account. Significant dispersion of the results for water-cement ratios from 0.28 to 0.35 with the large deviation of results can be observed. When the water-cement ratio increases, compressive strength also has less dispersed results but the dispersion is smaller and the differences between the results are less pronounced than the aforementioned range of water-cement factor.

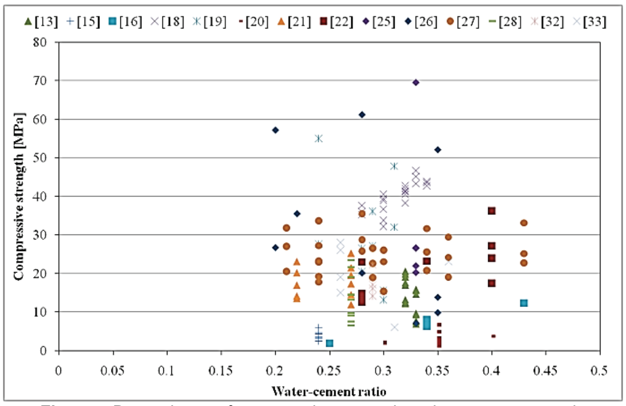

Figure 5 Dependence of compressive strength and water-cement ratio

Tab. 3 shows correlations coefficients of compressive strength, porosity and mass density in porous concrete. Based on the presented coefficients of correlations, it is evident that the values are significantly high as compared to many different types of mixtures, according to the composition, fraction of aggregates, type of aggregates and water-cement ratio. The values of correlation coefficients are in the range of strong correlation.

Table 3 Correlation coefficients for compressive strength, void and density of pervious concrete

	Compressive strength (MPa)	Void (%)	Density (kg/m^3)
Compressive strength (MPa)	1		
Void (%)	0.764	1	
Density (kg/m^3)	0.889	0.852	1

3.2 Flexural Strength

Addition of a small sand content (approximately 5% relative to the total aggregate weight) increases the flexural strength of the pervious concrete [34]. Flexural strength is increased by adding the polymer additives and using smaller aggregate fractions. Flexural strength ranges from 1 to 3.8 MPa.

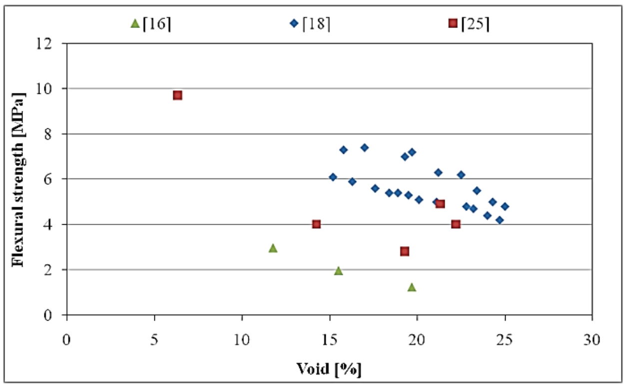

Figure 6 Dependence of flexural strength and void

The flexural strength dependence to porosity is shown in Fig. 6. It is noticeable that the dissipation of summarized and analyzed results is increased and it is not possible to establish a reliable correlation. While porosity increases, the dispersion of flexural strength results reduces (and vice versa).

3.3 Tensile Strength at Splitting

This test procedure appeared much later than the traditional bending testing and it is considered as a quite reliable procedure for determining the tensile strength of concrete [35].

Comparative values of tensile strength at splitting according to the density and porosity of analyzed researches are given in Fig. 7 and Fig. 8.

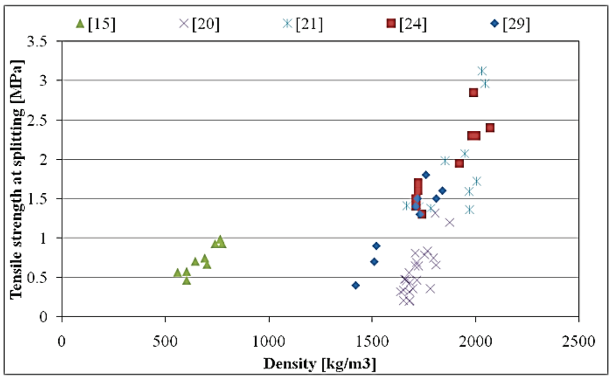

Figure 7 Dependence of tensile strength at splitting and density

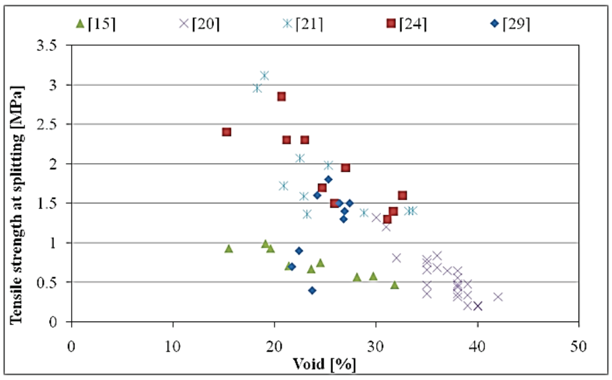

Figure 8 Dependence of tensile strength at splitting and porosity

Table 4 Correlation coefficients for tensile strength at splitting, density and void of pervious concrete

	Tensile strength at splitting (MPa)	Density (kg/m^3)	Void (%)
Tensile strength at splitting (MPa)	1		
Density (kg/m^3)	0.782	1	
Void (%)	0.715	0.190	1

With the analysis of the results, it can be seen that there is a big dispersion of the results for the same density and porosity so unique correlation between the tensile strength at splitting and the density cannot be established, as well as between the tensile strength at splitting and porosity in the porous concrete. However, with Fig. 7 and Fig. 8 correlation trend can be observed that shows the increase of the tensile strength at splitting with increase of density, and reduced tensile strength at splitting with increased porosity. When density increases, it is observed that the tensile strength at splitting varies, i.e. the dispersion of the results is significant and sometimes the same values of tensile strength at splitting are obtained for samples with the same density. Tests with different porosity show similar pattern, decreasing of the porosity leads to greater dispersion of tensile strengths, while increasing of the porosity for the same measure leads to reduced dispersion of tensile strengths at splitting.

The values of correlation coefficients for tensile strength at splitting, density and void are shown in Tab. 4. Correlation coefficients belong to the group of strong and very poor correlation.

3.4 Density

Density is the most important "special" pervious concrete property. Depending on the concrete state, there are different densities to be determined:

- density in the fresh state;
- density of naturally wet hardened concrete;
- density of completely dry hardened concrete.

Density in the fresh state represents the mass per volume unit immediately after casting. It contains a total amount of water, effective water and water added due to the aggregate absorption. Density of concrete in its natural wet condition is a mass of wet concrete in the volume unit of hardened concrete in construction. Concrete density in completely dry condition is a mass per volume unit of concrete dried at temperatures of 105-110 °C until a constant mass is obtained [9-11]. The density of pervious concrete usually is 1600-2000 kg/m^3.

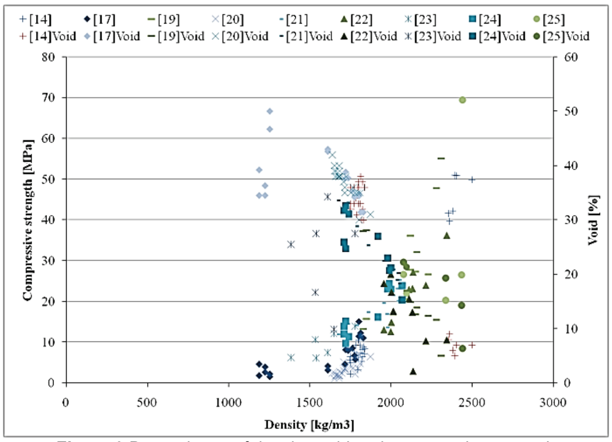

Figure 9 Dependence of density, void and compressive strength

With analysis of the results of density dependence on the porosity and compressive strength (Fig. 9), it can be concluded that there is a lot of dispersion of results for the same value of density, so that it is also not possible to establish a unique correlation between the above mentioned tests. The figure is prepared so that next to the referenced paper, a term "void", refers to the value of the porosity. By increasing, the value of density, the compressive strength increases, and the porosity decreases (and vice versa). In Fig. 9 the analyzed results of referenced results are shown and in Tab. 2 these results are summarized.

3.5 Frost Resistance

Concrete frost resistance testing is determined by means of two methods, destructive and non-destructive method. The number of samples for testing with destructive method depends on the established grade of frost resistance. Aerants have a significant effect on the frost resistance; they improve the properties of pervious concrete mixture and prevent rapid weight loss after exposure to a small number of exposure cycles. The presence of tiny rubber aggregate particles for the preparation of samples improves the properties of porous concrete mixture and also reduces the weight loss. For testing of pervious concrete pavement, it is necessary to conduct 200 to 300 cycles of tests depending on the type of aggressive environment, types of concrete and climatic zone.

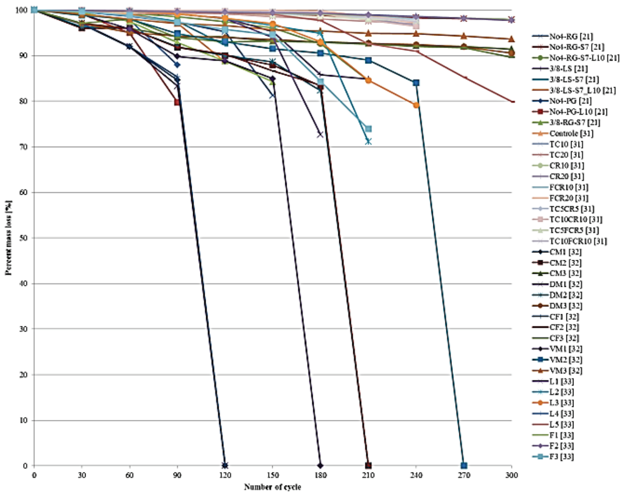

Figure 10 Frost resistance of pervious concrete

The main factors that lead to the concrete destruction are the internal stresses that occur during the freezing of water in the concrete pores. Internal stresses are the result of the increase of the ice volume by 9% relative to the appropriate quantity of liquid water. To prevent a destruction of concrete due to freezing of water it is most effective to sufficiently low water-cement ratio, the addition of recycled rubber. Other, various additives can also be applied, particularly aerants. In the literature it can be found that for testing of the frost effects various number of cycles are conducted ranging from 25 to 300 cycles [21, 31-33]. Fig. 10 shows an overview of the analyzed papers where the frost resistance is tested. It shows the dependence of mass loss and the number of freeze-thawing cycles for porous concrete. The results showed that the sand content, particles of recycled rubber, and aerates help pervious concrete to be frost resistant and to withstand up to 300 cycles. In the analyzed papers, it is proved that it is best to use natural aggregate with addition of certain amounts of sand, particles of recycled rubber and chemical additives (Table 2) for production of porous concrete mixture resistant to frost. Those samples have relatively little mass loss during the frost effect cycles and can resist 300 or 240 cycles depending on the analyzed paper and the testing conditions. Research results [31] showed that they resisted 240 cycles with weight loss of about 4%, what supports the conclusion that samples with the addition of rubber improve pervious concrete samples by making them more resistant to frost.

3.6 Abrasion Resistance

Due to the rough surface texture and open pores in porous concrete, abrasion and flaking over coarse aggregate may be potential problems in places where salt is used for removing snow from the roadway surface. This is one reason why the pervious concrete is not used for making highways and heavy traffic, but testing has shown that snow melting occurs more quickly in the pervious concrete than in the normal concrete surfaces [36].

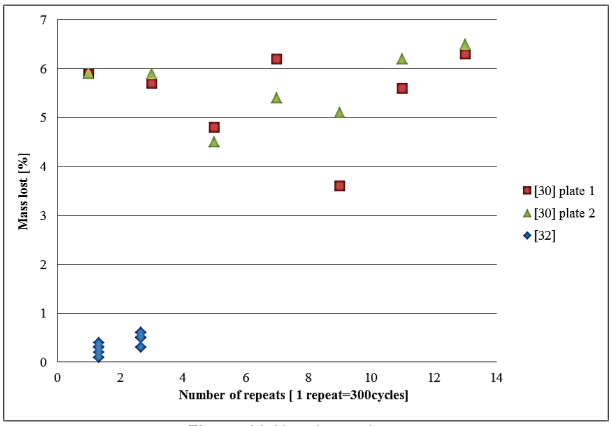

Figure 11 Abrasion resistance

Abrasion as a manner of mechanical wear of concrete is very important for concrete durability assessment. This phenomenon is especially pronounced in high-traffic areas, pedestrian paths and parking lots, and in the design of such structures special attention should be given to abrasion resistance. Concrete is more resistant to wear if it has higher compressive strength, meaning that crushed stone aggregate with the addition of smaller amounts of tiny aggregate fraction has to be used as well as high class cement with low water-cement ratio. Therefore, the plasticizers and superplasticizers are used to reduce the required water amount, since the separation of the cement paste on the surface must not be allowed. Abrasion resistance is analyzed in the papers [30-32] with different types of aggregates that were used, different fractions and different number of cycles (Tab. 2). In Fig. 11 the summarized analysis of results is presented with the dependence of mass loss against the number of cycles (with one test reaching 300 cycles). It is noted that the dispersion of the results is large and it is not possible to define a reliable correlation, while the number of repetitions increases, the loss of mass increases too. With the participation of additives and certain types of aggregates in the work [32], there is a small mass loss in relation to the analyzed results given in the paper [30] where coarse aggregate fractions without chemical and/or mineral supplements are used. Significantly better abrasion resistance testing results are achieved with the addition of recycled rubber, the paper [31] also shows that when the amount of recycled rubber increases, the mass loss is reduced during the abrasion resistance tests.

3.7 Permeability Coefficient

The values of permeability coefficient depend on the preparation material and casting site. Typical values for the permeability coefficient range from 0.2 cm/s up to 0.5 cm/s, and, in the laboratory tests, can even reach up to 1.2 cm/s or more [2]. Permeability coefficient is affected by the size of the aggregate used for the mixture, water-cement ratio and the amount of pores. For porosity from 20 to 25%, the permeability coefficient is about 0.01 m/s [6]. One of the most important properties of pervious concrete is the ability of water to go through its matrix. The permeability rate or the permeability coefficient of the pervious concrete is particularly related to the porosity and the size of pores.

According to the analysis of permeability coefficient dependence on porosity (Fig. 12), it can be seen that there is a large dispersion of results for the same amount of porosity so that reliable correlation between the above mentioned tests cannot be established. It is observed, from Fig. 12, when value of porosity increases dispersion of the permeability coefficient results also increases (and vice versa).

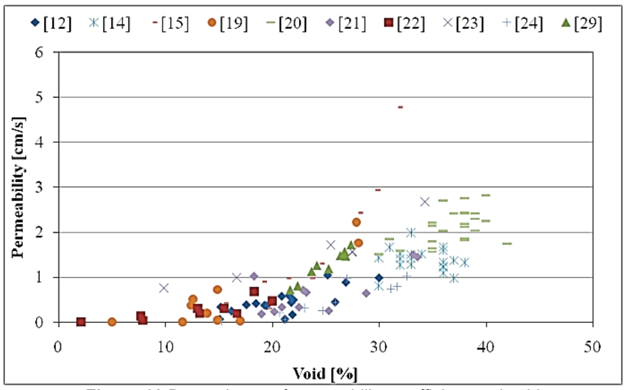

Figure 12 Dependence of permeability coefficient and void

3.8 Void

The amount of the porosity (void) for pervious concrete ranges from 15 to 35%. Content of the pores affects the permeability coefficient and strength, and while the porosity increases the permeability coefficient increases too, meanwhile strength is reduced. There are three different types of pores (void) in the pervious concrete, i.e. pores in the cement paste, aggregate pores and pores in the mixture.

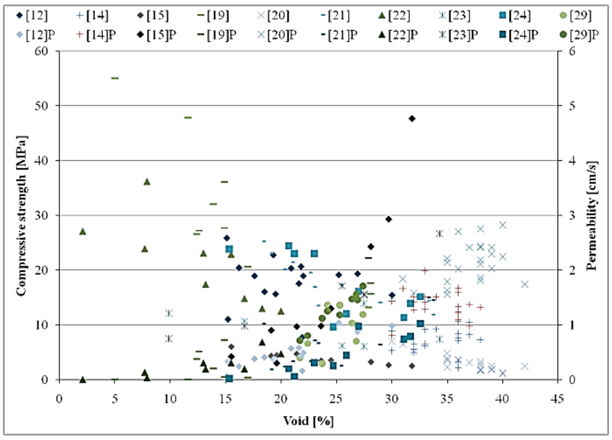

Figure 13 Dependence of void, compressive strength and permeability coefficient

The size of pores in the pervious concrete is one of the main factors that affect its properties. Large volume pores are recommended, because they have smaller risk of clogging [7]. Replacement of smaller size aggregates with a higher percentage of larger aggregate sizes increases the size of pores. This is conditioned by the fact that the space between large grains remains empty due to lack of smaller size aggregate that filled it in normal concrete [37]. The amount of porosity affects the compressive strength, flexural strength, tensile strength at splitting, permeability coefficient and frost resistance.

According to the analysis of relationship between the void, compressive strength and permeability coefficient (Fig. 13), it can be seen that large dispersion of results exists for the same amount of porosity, therefore making it impossible to define reliable correlation between the above mentioned tests. In Fig. 13, next to the referred paper, a marking "P" is used to depict the values of permeability coefficient. It can be concluded that, while porosity increases, the compressive strength decreases with the increase of the permeability coefficient. Fig. 13 shows the test results which are listed and summarized in Tab. 2.

Correlation coefficients for compressive strength, permeability and void coefficient of pervious concrete are shown in Tab. 5. The coefficient values of the analyzed physical-mechanical properties belong to the group of strong correlation.

Table 5 Correlation coefficients for compressive strength, void and permeability coefficient of pervious concrete

	Compressive strength (MPa)	Void (%)	Permeability coefficient (cm/s)
Compressive strength (MPa)	1		
Void (%)	0.771	1	
Permeability coefficient (cm/s)	0.773	0.834	1

4 DISCUSSION OF RESULTS

After all the analyzed data, it is evident that significantly large coefficients of correlations are achieved, whereby different sorted types of mixtures are shown in Tab. 2.

Fig. 14, 15 and 16 show the dependence of porosity, compressive strength and permeability coefficient, obtained by equations from 1 to 6, with different types of aggregates (natural, lightweight and recycled aggregates).

$$f_{cs} = -0.0078 \cdot v^2 - 0.389 \cdot v + 29.526 \quad (1)$$

$$f_{cs} = 0.0734 \cdot v^2 - 4.7859 \cdot v + 79.947 \quad (2)$$

$$f_{cs} = 0.0303 \cdot v^2 - 1.4897 \cdot v + 24.089 \quad (3)$$

$$P = 0.0016 \cdot v^2 - 0.0077 \cdot v - 0.00432 \quad (4)$$

$$P = 0.0103 \cdot v^2 - 0.2457 \cdot v + 1.5041 \quad (5)$$

$$P = 0.0115 \cdot v^2 - 0.3675 \cdot v + 3.496 \quad (6)$$

Where the terms used in equations are: f_{cs} - compressive strength after 28 days (MPa), v - void (%), P - permeability coefficient (cm/s).

Presented equations are obtained as a second order polynomial, where (1) and (4) show the dependence for the natural aggregates, (2) and (5) show the dependence for the lightweight aggregates, and (3) and (6) for recycled aggregates. These equations were obtained on the basis of analyzed referenced papers, that investigated the effects of various aggregate fractions, water-cement ratio and chemical and/or mineral supplements on pervious concrete (Tab. 2).

Fig. 14 shows the results of compressive strength and permeability coefficient depending on the void of the pervious concrete made with natural aggregate. Natural aggregate is aggregate obtained by crushing rock material (crushed limestone) and natural gravel. Analyzed diagram is used to determine the optimal compressive strength and permeability coefficient depending on the amount of pores in the concrete mixtures that are made from natural aggregates.

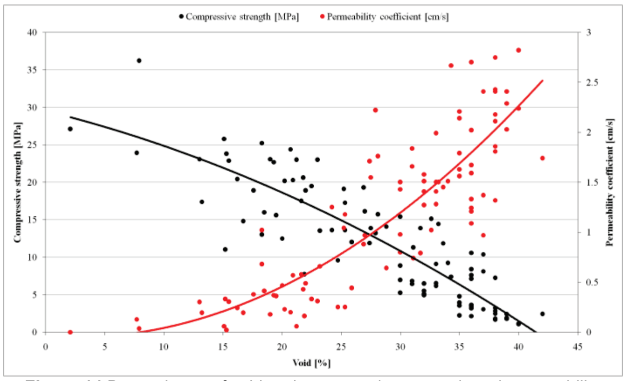

Figure 14 Dependence of void and compressive strength and permeability coefficient of natural aggregate

Tab. 6 presents the correlation coefficients of compressive strength, void and permeability coefficient at pervious concrete with natural aggregate. The values of coefficients belong to a group of strong correlations with determination error to a maximum of 20%, which is not a great value, because the different kinds of mixtures are analysed.

Table 6 Correlation coefficients of compressive strength, void and permeability coefficient at pervious concrete mixtures with natural aggregate

	Compressive strength (MPa)	Void (%)	Permeability coefficient (cm/s)
Compressive strength (MPa)	1		
Void (%)	0.875	1	
Permeability coefficient (cm/s)	0.828	0.874	1

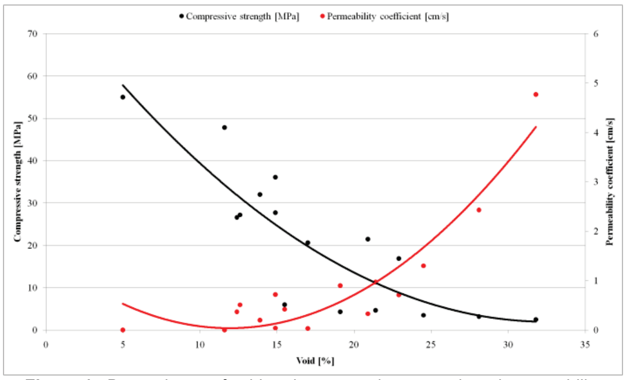

Figure 15 Dependence of void and compressive strength and permeability coefficient of lightweight aggregate

Fig. 15 illustrates a similar diagram as in Fig. 14, wherein there are shown the pervious concrete mixtures made from lightweight aggregate. The graph also has a role in determining the approximate compressive strength and permeability coefficient in a certain amount of voids that are created in preparing pervious concrete mixtures of lightweight aggregate.

The coefficients of correlations between compressive strength, void and permeability coefficient at pervious concrete made with lightweight aggregate are shown in Tab. 7. The values of coefficients belong to a group of very strong and strong correlation, but smaller number of data is analyzed in relation to the pervious concrete mixtures made from natural aggregate. The values of errors for analyzed results are maximum achieved up to 25%.

Table 7 Correlation coefficients of compressive strength, void and permeability coefficient at porous concrete mixtures with lightweight aggregate

	Compressive strength (MPa)	Void (%)	Permeability coefficient (cm/s)
Compressive strength (MPa)	1		
Void (%)	0.866	1	
Permeability coefficient (cm/s)	0.754	0.941	1

After presenting pervious concrete mixtures that are made of natural and lightweight aggregate, the pervious concrete mixture made of recycled aggregates remains to be shown (Fig. 16). The image shows that there are noticeably fewer authors that analyzed the pervious concrete mixtures made from recycled aggregate, where correlation coefficients vary significantly.

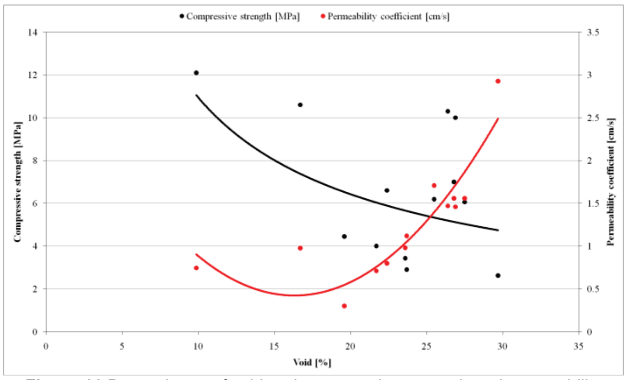

Figure 16 Dependence of void and compressive strength and permeability coefficient of recycled aggregate

Table 8 Correlation coefficients of compressive strength, void and permeability coefficient at pervious concrete mixtures with recycled aggregate

	Compressive strength (MPa)	Void (%)	Permeability coefficient (cm/s)
Compressive strength (MPa)	1		
Void (%)	0.432	1	
Permeability coefficient (cm/s)	0.435	0.909	1

Tab. 8 shows the correlation coefficients of compressive strength, void and permeability coefficient at pervious concrete with recycled aggregate. Amounts of analyzed errors ranging from 10% to 55%, which is significantly larger deviation from pervious concrete mixtures made of natural and lightweight aggregate. The coefficients belong to a group of very strong and very poor correlation.

It is noted that when the porosity decreases the compressive strength increases fast. Similar is observed for mixtures with lightweight aggregates. Meanwhile this increase is slower when natural and recycled aggregates are used. A similar principle applies to permeability coefficient; it increases with the increase of porosity. Significant results and high increase is observed primarily in mixtures that are made from lightweight aggregate, then recycled aggregates, while in mixtures that are made from natural aggregate results gradually increase when compared to previous two types of aggregates.

Based on analyzed papers and determined equations, it can be concluded that all three types of aggregates can be used for production of pervious concrete mixture, providing that we define the specific use and the environment in which pervious concrete is to be placed in order to choose the best possible type of aggregate and a certain amount of porosity to obtain better abrasion layer.

5 APPLICATION OF PERVIOUS CONCRETE IN SERBIA

In Serbia, pervious concrete provides an area of high permeability, it thereby significantly reduces the risk of floods and total cost of maintaining rainwater drainage network. Unique formulation of this type of concrete provides easy casting without fine particles, which is on the other side robust during the process of construction and maintenance. The composition of aggregates is adjusted to provide the minimum compactness and required uniform porosity of hardened concrete, while the cement paste gives the latest properties in fresh and hardened state. Careful selection of materials with a special recipe of concrete mixtures insures the concrete whose properties can be defined in advance and makes the management of atmospheric waters very efficient [38].

Figure 17 Application of pervious concrete in Serbia

Pervious concrete mixture comprises the following: crushed stone aggregate fractions 4/8 mm or 8/11.2 mm without the presence of small aggregate particles, the water-cement ratio of approx 0.32 and 20% of pores. This mixture provides compressive strengths from 14 to 20 MPa, depending on the aggregate fraction and cement quantities during preparation of pervious concrete mixture. The amount of concrete permeability ranges from 300÷500 l/min/m^2 and this type of concrete in Serbia was applied to create parking spaces and footpaths [38]. The first use of pervious concrete started in 2014, for parking areas in the engineering building. After the first experience and good impressions, the development of walking and cycling paths started in some of the cities in Serbia. The first appearance of porous concrete in Serbia is shown in Fig. 17.

All pervious concrete car parks were constructed on the compacted permeable subgrade soil. So far, implementation and research in Serbia did not include waterproof subgrade with possibility of frosting. Research is mainly concentrated on compressive strength and permeability coefficient.

6 CONCLUSION

Based on comparative analysis of presented researches and review of the literature in this area, it can be concluded that pervious concrete is mostly made from various kinds of natural rock materials with different proportions of aggregates and various types of additives in concrete. Researches were conducted for pervious concrete with other aggregate types, such as recycled concrete, recycled brick, recycled rubber and lightweight aggregates.

Application in Serbia is in its beginnings and it is mainly concentrated on parking spaces, pedestrian and cycle paths in parks and similar. It is estimated that pervious concrete application would be wider if more extensive research and testing was conducted, especially since the society is more sensitive to preservation of the environment and responsible use of natural resources.

Finally, it can be concluded that great influence on all properties of hardened pervious concrete has primarily porosity, then whether natural or recycled aggregate was used, shape of aggregates (pointed or spherical), water-cement ratio, small size aggregate content and presence of additives. All of these parameters are interrelated and need to be harmonized in order to achieve maximum compressive strength, flexural strength, tensile strength at splitting, abrasion resistance and frost resistance.

7 REFERENCES

[1] Putman, B. J. & Neptune, A. I. (2011). Comparison of test specimen preparation techniques for pervious concrete pavements. *Construction and Building Materials*, 25, 3480-3485. https://doi.org/10.1016/j.conbuildmat.2011.03.039

[2] Tennis, P. D., Leming, M. L., & Akers, D. J. (2004). Pervious concrete pavements. *Technical report*, EB302.02. / Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland.

[3] Schaefer, V. R., Wang, K., Suleiman, M. T., & Kevern, J. (2006). Mix design development for pervious concrete in cold climates. *Technical report*, National Concrete Pavement Technology Center, Iowa State Univ., Ames, Iowa.

[4] Felja, M., Ćosić, K., & Netinger, I. (2013). Primjena poroznog betona u kolničkim konstrukcijama. *Elektronski časopis građevinskog fakulteta Osijek, 4*(7), 68-75.

[5] Yang, J. & Jiang, G. (2003). Experimental study on properties of pervious concrete pavement materials. *Cement and Concrete Research*, 33, 381-386.

[6] Blažok, D. (2010). Propusni beton za kolnike. *Tehnički glasnik, 4*(1-2), 15-18.

[7] American Concrete Pavement Association: Green Highways Environmentally and Economically Sustainable Concrete Pavements - concrete pavement research and technology

special report, (2007), http://www.pavements4life.com/QDs/SR385P.pdf (Accessed on 10.02.2016)
[8] Ghafoori, N. & Dutta, S. (1995). Development of no-fines concrete pavement applications. *Journal of Transportation Engineering, 121*(3), 283-288. https://doi.org/10.1061/(ASCE)0733-947X(1995)121:3(283)
[9] Muravljov, M. (2005). *Građevinski materijali*, Građevinska knjiga, Republika Srbija, Beograd.
[10] Muravljov, M. (2010). *Osnovi teorije i tehnologije betona*, Građevinska knjiga, Republika Srbija, Beograd.
[11] Skenderović, B. & Kekanović, M. (2011). *Građevinski materijali*, AGM knjiga, Republika Srbija, Beograd.
[12] Kevern, J. T. (2008). Advancements in pervious concrete technology. *Doctoral thesis*, Iowa State University, Ames, Iowa.
[13] Sumanasooriya, M. S. & Neithalath, N. (2011). Pore structure features of pervious concretes proportioned for desired porosities and their performance prediction. *Cement & Concrete Composites, 33*, 778-787. https://doi.org/10.1016/j.cemconcomp.2011.06.002
[14] Aoki, Y. (2009). Development of pervious concrete. *Master thesis*, Technical University of Sydney, Australia.
[15] Zaetang, Y., Wongsa, A., Sata, V., & Chindaprasirt, P. (2013). Use of lightweight aggregates in pervious concrete. *Construction and Building Materials, 48*, 585-591. https://doi.org/10.1016/j.conbuildmat.2013.07.077
[16] Ling, L. Y. (2010). Mechanical properties of 10 mm single-sized recycled aggregates porous concrete with wood fiber. *Bachelor thesis*, Faculty of Civil Engineering, Technical University of Malesia.
[17] Kim, H. K. & Lee, H. K. (2010). Influence of Cement Flow and Aggregate type on the Mechanical and Acoustic Characteristic of Porous Concrete. *Applied Acoustic, 71*(7), 607-615. https://doi.org/10.1016/j.apacoust.2010.02.001
[18] Chen, Y., Wang, K., & Liango, D. (2012). Mechanical properties of pervious cement concrete. *Journal of Central South University, 19*, 3329-3334. https://doi.org/10.1007/s11771-012-1411-9
[19] Kevern, J. T., Schaefer, V., & Wang, K. (2008). Portland Cement Pervious Concrete: A Field Experience from Sioux City. *The Open Construction and Building Technology Journal, 2*, 82-88. https://doi.org/10.2174/1874836800802010082
[20] Ibrahim, A., Mahmoud, E., Yamin, M., & Patibandla, V. C. (2014). Experimental study on Portland cement pervious concrete mechanical and hydrological properties. *Construction and Building Materials, 50*, 524-529. https://doi.org/10.1016/j.conbuildmat.2013.09.022
[21] Schaefer, V. R., Wang, K., Suleiman, M. T., Kevern, J. (2006). Mix design development for pervious concrete in cold climates. T*echnical report*, National Concrete Pavement Technology Center, Iowa State Univ., Ames, Iowa.
[22] Sonebi, M. & Bassuoni, M. T. (2013). Investigating the effect of mixture design parameters on pervious concrete by statistical modeling. *Construction and Building Materials, 38*, 147-154. https://doi.org/10.1016/j.conbuildmat.2012.07.044
[23] Sriravindrarajah, R., HuaiWnag, N. D., & Wen Ervin, L. J. (2012). Mix Design for Pervious Recycled Aggregate Concrete. *International Journal of Concrete Structures and Materials, 6*(4), 239-246. https://doi.org/10.1007/s40069-012-0024-x
[24] Kevern, J. T., Wang, K., & Schaefer, V. R. (2008). A Novel Approach to Characterize Entrained Air Content in Pervious Concrete. *Journal of ASTM International, 5*(2), 1-12.
[25] Ćosić, K., Korat, L., Ducman, V., & Netinger I. (2015). Influence of aggregate type and size on properties of pervious concrete. *Construction and Building Materials, 78*, 69-76. https://doi.org/10.1016/j.conbuildmat.2014.12.073
[26] Yang, J. & Jiang, G. (2003). Experimental study on properties of pervious concrete pavement materials. *Cement and Concrete Research, 33*, 381-386. https://doi.org/10.1016/S0008-8846(02)00966-3
[27] Girish, S. & Manjunath Rao, R. (2011). A Step towards Mix Proportioning Guidelines for Pervious Concrete. *International Journal of Earth Sciences and Engineering, 4*(6), 768-771.
[28] Gesoglu, M., Guneysis, Khoshnaw, G., & Ipek, S. (2014). Investigating properties of pervious concretes containing waste tire rubbers. *Construction and Building Materials, 63*, 206-213. https://doi.org/10.1016/j.conbuildmat.2014.04.046
[29] Sata, V., Wongsa, A., & Chindaprasirt, P. (2013). Properties of pervious geopolymer concrete using recycled aggregates. *Construction and Building Materials, 42*, 33-39. https://doi.org/10.1016/j.conbuildmat.2012.12.046
[30] Chen, Y., Wang, K., & Zhou, W. (2013). Evaluation of surface textures and skid resistance of previous concrete pavement. *Journal of Central South University, 20*, 520-527. https://doi.org/10.1007/s11771-013-1514-y
[31] Gesoglu, M., Guneysis, Khoshnaw, G., & Ipek, S. (2014). Abrasion and freezing-thawing resistance of pervious concretes containing waste rubbers. *Construction and Building Materials, 73*, 19-24. https://doi.org/10.1016/j.conbuildmat.2014.09.047
[32] Amde, A. M. & Rogge, S. (2013). *Development of High Quality Pervious Concrete Specifications for Maryland Conditions*. Department of Civil and Environmental Engineering, University of Maryland, College Park.
[33] Shu, X., Huang, B., Wu, H., Dong, Q., & Burdette, E. G. (2011). Performance comparison of laboratory and field produced pervious concrete mixtures. *Construction and Building Materials, 25*, 3187-3192. https://doi.org/10.1016/j.conbuildmat.2011.03.002
[34] Neithalath, N. (2004). Development and Characterization of Acoustically Efficient Cementations Materials. *Doctoral thesis*, Purdue University, West Lafayette.
[35] Grupa autora. (1995). *Beton i armirani beton – Tom 1 Priručnik*. Građevinski fakultet Univerzitet u Beogradu, Beograd.
[36] Handbook for Pervious Concrete Certification in Greater Kansas City: http://www.concretepromotion.com/pdf/Pervious%20Concrete%20Handbook.pdf (Accessed on 10.02.2016)
[37] Stojanović, M., Šešlija, M., Malešev, M., & Radonjanin, V. (2014). Svojstva propusnog betona i mogućnost njihove primene u savremenoj putogradnji. *Proceedings of the First Serbian Road Congress* / Beograd, 829-838.
[38] Hydromedia 2014. http://www.lafarge.rs/Hydro/Hydromedia-tehnicki-list.pdf?xtmc=hydromedia&xtcr=3 (Accessed on 10.02.2016)

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